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Soil N cycling in harvested and pristine Boreal forests and peatlands

Cherie J. Westbrook [a,*], Kevin J. Devito [b], Craig J. Allan [c]

[a] Department of Geography, Centre for Hydrology, University of Saskatchewan, Saskatoon, Saskatchewan, Canada S7N 5A5
[b] Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada T6E 2G9
[c] Department of Geography and Earth Sciences, University of North Carolina at Charlotte, Charlotte, NC 28223, USA

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Abstract

The heterogeneous Boreal Shield forest in Canada is one of the most extensive pristine forests remaining in the world and is being intensely harvested. We studied the spatial variability of organic and inorganic N cycling processes in three Boreal Shield catchments in northwestern Ontario for 2 years before and 1 year following clearcutting. Net N mineralization rates were similar among upland conifer, upland deciduous and peatland stands, ranging from negligible to 150 mg kg^{-1} in the forest floor/peat soils and −30 to 40 mg kg^{-1} in mineral soils of the upland stands over the growing season. Net nitrification rates were generally negative, <10% of net mineralization rates, and similar among the landscape units. Reciprocal transplants of forest floor/peat and mineral soil from the uncut and cut stands indicated that changes in environmental conditions in the clearcut influenced net N mineralization by 50-fold and nitrification rates by nine-fold in the peatlands but not the coniferous uplands. Net inorganic N cycling rates measured the 1st year following clearcutting were within the natural range of variability, which is consistent with previous studies in northern coniferous and aspen forests. In contrast with the literature however, no difference in soil dissolved organic N mobilization rates (peatland stand range: 0.2 to 4.8 mg kg^{-1} d^{-1}; upland coniferous stand range: −0.1 to 2.3 mg kg^{-1} d^{-1}) were found between uncut and recently clearcut stands.

Keywords: Boreal forest; Canadian shield; Dissolved organic nitrogen (DON); Forest harvesting; Net N mineralization; Nitrification; Nitrogen; Peatlands

1. Introduction

The Boreal Shield ecozone of Canada is one of the most extensive pristine forests remaining in the world, and is subject to high logging pressure (400,000 ha annually: Environment Canada, 2000; Kronberg and Watt, 2000). Limited N availability, low soil temperature, and summer soil moisture deficits have been identified as the most important growth limiting factors in boreal forests (Post et al., 1992; Binkley and Hogberg, 1997). Forest harvesting may increase the availability of N through increasing soil temperature and antecedent moisture (Chapin, 1996; Redding et al., 2002). An increase in N may have ramifications for soil fertility, which is important in successful forest renewal (Jurgensen et al., 1997) and the export of waterborne nitrate (Sollins and McCorison, 1981).

A complex mosaic of peatlands and coniferous and deciduous uplands characterizes the Boreal Shield region. Soil N availability and net N mineralization and nitrification rates have been found to vary with tree species composition in temperate and boreal forests (Min et al., 1999). Contrasts among landscape units with different tree species composition have been linked to differences in soil organic matter content, litter N content, C/N ratios, soil moisture, temperature and topographic position (Devito et al., 1999; Lamontagne, 1998; Hill and Shackleton, 1989; Ohrui et al., 1999; Stottlemyer et al., 1995; Zak and Grigal, 1991). Since trees from all landscape units are removed during forest harvesting in this region, a characterization of the spatial variation in N cycling rates at the catchment scale is needed to predict the controls regulating inorganic and potentially organic N losses.

The effects of forest harvesting on N dynamics have been explored for coniferous and deciduous upland stands in temperate forests. General conclusions are that net N mineralization and nitrification commonly increase following forest harvesting (Feller and Kimmins, 1984; Hendrickson et al., 1989; Munson and Timmer, 1995; Paavolainen and Smolander, 1998; Reynolds et al., 2000), and then decline as stands age (Bormann and Likens, 1979; Piatek and Allen, 1999;

* Corresponding author. Tel.: +1 306 966 1818; fax: +1 306 966 1428.
E-mail address: cherie.westbrook@usask.ca (C.J. Westbrook).

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Kranabetter and Coates, 2004). There is however a growing body of literature showing limited effects of forest harvesting in northern coniferous and deciduous forests (Paré and Van Cleve, 1993; Carmosini et al., 2003; Grenon et al., 2004; Lapointe et al., 2005). The effects of forest harvesting on dissolved organic N (DON) have been inconclusive. Studies in upland stands have shown DON may be higher (Smolander et al., 2001) or lower (Carignan et al., 2000; Smith et al., 2000; Hannam and Prescott, 2003) after tree harvesting.

The effects of forest harvesting within or adjacent to peatlands on peatland N dynamics have not been well studied. Valley peatlands represent potentially critical interfaces regulating N export from catchments due to their relative abundance and position in the landscape (Devito and Dillon, 1993; Cirmo and McDonnell, 1997) and may be more sensitive to disturbance than drier upland stands. Peatland nitrogen dynamics are driven by their hydrological condition and thus tend to exhibit high spatial variation in N cycling processes (Devito and Dillon, 1993; Hill and Devito, 1997). Higher soil moisture and degree of soil anoxia has been shown to increase soil N availability post-harvest in a peatland (Walbridge and Lockaby, 1994). Additionally, altered soil microclimate and peat disturbance (rutting and compaction) may lead to higher N cycling rates in peatlands following harvest (Grigal and Brooks, 1997; Groot, 1987).

This study was part of a larger study examining the impacts of tree harvesting on terrestrial and aquatic ecosystems (Steedman and Kushneriuk, 2000). Herein we report on terrestrial N cycling processes at the catchment scale and the 1st year effects of forest harvesting on these processes. Concurrent measures of net N mineralization, net nitrification and DON mobilization were conducted to: (1) compare soil N cycling processes in coniferous upland, deciduous upland, and peatland stands; (2) determine the 1st year effects of forest harvesting on these three ecosystems; (3) assess whether changes in post-harvest N cycling processes were due to changes in environmental conditions or change in the nature of the soils.

2. General site description

This research was conducted between May 1996 and October 1998 in the Ontario Ministry of Natural Resources' Coldwater Lakes Experimental Watersheds (49°05′N and 92°10′W), northwestern Ontario, Canada. The landscape is a mosaic of coniferous (*Pinus banksiana* Lamb. and *Picea mariana* (Mill.) BSP) and deciduous (*Populus tremuloides* Michx. and *Betula papyrifera*) uplands, peatlands (*Picea mariana* (Mill.) BSP, *Ledum groenlandicum* and *Chamaedaphne calyculata*), and lakes. Mean annual precipitation (1971–2000) in Atikokan (Environment Canada station 6020379) was 740 mm with 30% falling as snow. April to October rainfall was 113%, 79%, and 98% of the long-term mean in 1996–1998. Snow water equivalent of the late winter snowpack was 130 mm in both 1996 and 1997 and only 5 mm in 1998. The mean January and July air temperatures are −17.6 and 19.2 °C, respectively. Mean evapotranspiration (ET) for the study area was 350 ± 40 mm, as calculated for 9 years using a simplified water budget approach (ET = precipitation − streamflow, assuming no change in soil moisture or groundwater storage on an annual basis). Mean inorganic N deposition, measured on-site between 1998 and 2002 with a bulk deposition collector, was 2.3 kg N ha^{-1}.

The bedrock geology is Archean granitic-gneissic (Zoltai, 1965). Glacial till is patchy, bouldery, and thin near the top of hillslopes and up to 1 m thick at the bottom of hillslopes. Mineral soils in the study area are of glacial-fluvial origin, comprised of silty loam to coarse sand and are classified as orthic dysteric brunisols. The forest floor 3–8 cm thick in uncut upland stands and 0–8 cm thick in cut upland stands. Peatlands have organic histols with a thickness of up to 1 m, and are hydrologically connected to the hillslopes primarily via subsurface flowpaths and occasionally by channelized surface flow following rainfall events.

3. Study design

3.1. Catchment-scale experiment

The design was a three-catchment replication with a pre- and post-treatment experimental approach examining the influence of tree harvesting on net N mineralization. The three catchments were within 5 km of one another and had similar bedrock geology, soil depth, and pre-treatment forest cover. The 9.8 ha reference (REF) and two experimental (9 ha EC1 and 19 ha EC2) headwater catchments were stratified by forest cover (aspen upland, conifer upland and peatland) in May 1996 and 14, 100 m transects throughout the three forest cover types were established in each catchment. Along each transect, five locations (hereafter plots) spaced approximately 20 m apart were sampled (methodology described later) during four incubation periods in each of the pre-treatment (1996, 1997) and post-treatment (1998) study years.

The treatment was clearcutting of the two experimental catchments between June 1 and 20 in 1998. Approximately 90% of the trees in EC1 and 95% of the trees in EC2 were removed with chainsaws. Trunks were dragged to the nearest road with cable skidders before being delimbed. Peat surfaces were highly disturbed as tree harvest occurred in June when the soils were moist. Compression of the peat surface by skidder tires resulted in many deep ruts that intersected the water table. The ruts occurred in a random pattern, occupying about half of the peatland surface. Harvesting caused much less physical disturbance of the soils in the mineral upland stands, leaving the soil horizons mostly intact.

3.2. Reciprocal transplant experiment

A field reciprocal transplant experiment of soils from mature (uncut) and harvested (cut) conifer upland and peatland stands was conducted during the time with the warmest soil conditions to isolate the effects of altered environmental conditions versus changes in the nature of the soil following harvesting on net N transformations (c.f. Prescott et al., 2003). Aspen upland stands were excluded from the experiment due to the lack of a suitable nearby uncut stand. Ten plots were established within each of